Professor Edward Orton's Talk on the Origin of the Rock Pressure of Natural Gas in the Trenton Limestone of Ohio and Indiana.

The Importance of the Product.

Natural gas derived from the Trenton limestone has supplied during the last year and is now supplying all the fuel and a considerable part of the artificial light that is used by at least four hundred thousand people in northwestern Ohio and in central Indiana. Within the same limits it is the basis of a varied line of manufactures, the annual product of which will make an aggregate of many millions of dollars. More than forty glass furnaces, not one of them three years old, are now in very successful operation within the territory named, while iron and steel mills, potteries and brick works, and a long list of factories in which cheap power is a desideratum, have been built up on all sides with wonderful rapidity.

The largest gas production of the Trenton limestone that has yet been reached is to be credited to the present year. A well drilled early last summer at Stuartsville, six miles north of Findlay, produced through the casing, a pipe 5⅝ inches in diameter, 28,000,000 cubic feet of gas every twenty-four hours. There are but few wells in any field that exceed these figures.

Most of the wells so reported have been estimated, not measured.

An equally astonishing advance has been made in the oil production of this rock within four counties of northwestern Ohio. Single wells drilled during the last year have begun their production at a rate of 10,000 barrels per day; and more than 200,000 barrels of total production are already to be credited to single wells of the new field, while a considerable number have passed the 100,000-barrel mark.

The Rock Pressure.

The rock pressure of the gas is a vital factor in all this production. To its energy is due the propulsion of the volatile fuel from the wells where it is released, through twenty, thirty, fifty miles of buried pipes, to the cities which it supplies with the unspeakable advantages of gaseous fuel. It is the same cause that lifts the oil from the rock in all flowing wells.

By rock pressure is meant the pressure which a guage shows in a well that is locked in after the drill has reached the gas reservoir. The iron tubing of the well becomes by this means a part of the reservoir, and the same conditions as to pressure are supposed to pertain to it that are found in the porous rock below.

The rock pressure of gas varies greatly in different fields and to a less, but still an important, extent in different portions of the same field. The highest rock pressure recorded in the Trenton limestone is about 650 pounds to the square inch, while there are considerable sections of the gas territory that never reach 300 pounds pressure per square inch. The original pressure in the Findlay field was 450 pounds, varying somewhat in wells of different depths. In the Wood county field, from which the largest amount of gas is now being conveyed to Ohio cities, the original pressure ranged from 420 to 480 pounds, the general pressure being counted 460 pounds to the square inch. There were occasional records made of still higher pressure in single wells, but of such cases the number is very small, and the existence of these anomalous pressures was short-lived.

Passing to the westward, the gas wells of Auglaize and Mercer counties show a decided reduction in original rock pressure as compared with Findlay, though the depths of the wells remain the same as in that field. The highest pressure recorded in Mercer county is 390 pounds to the square inch, but no guage was applied to the wells until they had been allowed to discharge without restraint for several months, while 375 and 350 pounds mark the extreme limit of other portions of this district.

In the Indiana field a still further reduction of rock pressure is to be noted. The range of the principal Indiana wells is between 250 and 325 pounds to the square inch. The Indiana gas wells, as compared with Ohio gas wells, are marked by a reduction in total depth, as well as in rock pressure, the figures for depth in the productive territory seldom or never passing one thousand feet.

How can these variations be accounted for? Back of this question is a larger one, viz: What is the origin of the rock pressure of natural gas?

Considering its importance, the main question has received less consideration than would naturally be expected. The known literature of the subject is very meagre. Professor J. P. Lesley, in the Annual Report of the Pennsylvania Survey for 1885, discussed the question at greater length than any other geologist, so far as I know. In a paper published in the *American Manufacturer* May 27, 1887, I threw out a few suggestions as to the cause of rock pressure, and these suggestions I afterward expanded into a more extended statement, in the sixth volume of the Geology of Ohio, page 96. Professor I. C. White suggested an explanation in the journal named above at an earlier date than either of those given.

The men who are engaged in the practical development of gas and oil fields make great account of rock pressure. It is the first fact that they inquire after in a new gas field. They appreciate its importance in whatever utilization of the gas they may propose, knowing that the distance of the markets that they can reach and the size of the pipes that they can employ are entirely dependent upon this element. These practical men, so called, are, as is well known, among the most venturesome of theorists, and a question like this would not be likely to be left unanswered by them. A certain rough correspondence that exists between the depth and the rock pressure of wells is made of great account in explanations that they offer. In other words, the pressure is supposed to be due to the weight of the overlying rocks; and next to this we find among them the expansive force of gas the favorite explanation of the phenomenon.

In the paper of Professor Lesley, already referred to, the learned author suggests the two possible explanations of rock pressure already named, and to this he adds a third, viz., hydraulic pressure; but he adds this explanation only to reject it as a true cause of the phenomenon under discussion. The absurdity of the more commonly received explanation of rock pressure, as due to the depth of the well—in other words to the weight of the overlying country, he sets in such clear light in his discussion that no further consideration of this is required on the part of those who are open to reason. Until we can prove, or at least render it probable, that the gas rocks have lost their cohesion and that they exist at the depths of storage in a crushed or comminuted state, no explanation can be based upon the weight of the overlying rock in accounting for the force with which the gas escapes from its reservoirs when they are penetrated by the drill. Professor Lesley throws the whole weight of his authority in favor of the view that the gas "produces its own pressure, like gas generated by chemical reaction in a closed vessel." This explanation certainly leaves something to be desired, for it fails to account for the most significant and important facts in this connection, viz., the differences of rock pressure in different localities and at different depths. To accept it brings us no advantage whatever, beyond the satisfaction that we may feel in having an answer at hand that can be promptly given to a troublesome inquiry.

For my own part, I have felt certain for more than two years that the rock pressure of gas in the Trenton limestone of Ohio and Indiana is hydrostatic in origin, and I have published a number of facts that seem to me to give support to this view. I find that some sagacious operators in the new gas and oil fields are coming to the same ground. They have become thoroughly satisfied by their own experiences that the root of rock pressure is to be found in the water column that stands connected with the porous rock in which the gas and oil are contained. In the present paper, I desire to present to the Geological Society a few facts and conclusions bearing upon the subject.

The Data for the Hydrostatic Theory.

The first question is, What are the facts as to the rock pressures of the gas rock in question, and what relations do they bear to the depth of wells and other conditions in the Trenton limestone? The answer is not as full and definite as may be expected, certainly not as may be desired. There is but one date in the development of a gas field in which the normal gas pressure can be ascertained, and that is when the first well reaches the reservoir and releases the long-imprisoned and greatly compressed gas. But often this favorable opportunity is lost, and guages are not applied to wells until the energy of the first flow is somewhat abated. Again, different wells in the same field, as Findlay for example, give different results. The wells vary with the depth at which the gas rock is found. This factor is found to be an essential one, as will presently be shown, in connection with rock pressure. Morever, guages are sometimes inaccurate, and their errors come in to confuse the study of the subject. Furthermore, the exact depth of the wells and the exact altitude of the surface where they are located cannot be ascertained in all cases. Small errors of this sort must be provided for, and there also enters into the discussion a question as to the specific gravity of the water which is to be made the moving force of gas and oil. The water found in association with these substances is never fresh. It is always saline, and often highly mineralized. The weight of fresh water to the square inch is 0.43285 pound for one foot in height (I use Professor Lesley's tables). The average weight of sea water is 0.445 pound to the square inch for one foot; but the mineral waters with which we find the Trenton limestone saturated often reach a much higher figure. An examination of several specimens shows that a column one foot high would weigh to the square inch 0.476 pound. In fact, some of these waters are more like bitterns, and their columns would equal or exceed 0.5 pound per foot.

Bearing these several sources of ambiguity or uncertainty in mind, we can consider the records of pressure, depth, and the other factors that are accessible. The figures as to pressure have already been summarized in a preceding paragraph, but they will be repeated in an accompanying tabular statement. Before coming to this, however, let me in the briefest terms review the conditions under which gas, oil, and salt water exist in the Trenton limestone. The uppermost beds of the great Trenton formation in northwestern Ohio, central and northern Indiana, Michigan, Illinois and Wisconsin consist of a porous dolomite, five, fifty, one hundred, or even one hundred and fifty feet in thickness. Sometimes the dolomite is found in a continuous body, but oftener in interrupted beds. This part of the formation has outcrops in the Manitoulin Islands of Lake Superior, and in the Galena limestone of Illinois and Wisconsin. In the gas and oil fields, it is found lying in terraces and monoclines, or flat arches, eight hundred to fifteen hundred feet below the surface; and these several features effect the separation of the varied contents of the porous rock. The boundaries of gas, oil and salt water are easily determinable and are scrupulously maintained in the rock, except that as soon as development begins the salt water is always the aggressive and advancing element. When the drill descends into the gas rock proper, dry gas escapes; when into the contiguous and lower-lying terrace, oil accompanied with gas appears, as already described; but at a little lower level salt water is struck, and this rises promptly in the well, sometimes to the point of overflow. Far out from the narrow ridges or restricted terraces where gas and oil are found the salt water reigns undisturbed, and wherever reached by the drill it rises in the wells as in those already described. It would be in the highest degree absurd to count the little pockets of gas that are found in the arches the cause of the ascent of this ocean of salt water a score or a hundred miles away. The rise of the salt water is unmistakably artesian. It depends on hydrostatic pressure, as does the flow of all artesian wells, and its head must be sought, as in other like flows, in the higher portions of the stratum that are contiguous.

The nearest outcrops of this porous Trenton have been already named. They are found in the shores of Lake Superior at an altitude of about six hundred feet above tide. It is certainly significant that when an abundant flow of salt water is struck in a boring in northern Ohio or in Indiana, no matter at what depth, it rises generally about to the level of Lake Superior; or, in other words, about six hundred feet above tide. If the mouth of the well is below this level, as is the case in the Wabash valley, the salt water overflows. On the shore of Lake Erie the water rises to within 20 feet of the surface; in Findlay to within 200 feet. The height to which the salt water rises in any portion of the field is one of the elements to be used in measuring the force which can be exerted on the gas and oil that are caught in the traps of the terraces and arches of the porous Trenton limestone.

Why, then, is not the rock pressure of the gas the same in all portions of the new horizon? For the obvious reason, I reply, that there is a varying element involved, viz., *the depth of the rock below sea level.* The surface elevations at the wells vary greatly, and the wells of the same depth consequently find the gas rock in very different relations to sea level.

The Test of the Hydrostatic Theory.

It is obvious that if an explanation of the rock pressure of the Trenton limestone gas is attempted on this basis, there are facts enough now at command to substantiate or overthrow it. By the facts it must stand or fall. In the accompanying table I have indicated the following lines of facts as to strictly representative wells in the leading districts of the new gas fields, viz.: (1) location, (2) depth at which gas is found, (3) relation of this depth to sea level, (4) the initial rock pressure of the gas. In regard to the last line of facts I have taken, in almost all cases, figures that I have myself verified. (5) A fifth column I add, in which the pressure due in the particular well is calculated from the two following elements, viz., an assumed elevation of the salt water to the Lake Superior level, or six hundred feet above tide; and, secondly, an assumed specific gravity of the salt water of the Trenton of 1.1, which gives a weight of 0.476 pound to the foot.

Locations.	Depth to Gas.	Relation of Gas Rock to Sea Level.	Original or first Observed Pressure.	Calculated Pressure. 1′=0.476 lb.
Ohio.				
Tiffin Loomis & Lyman Well,	1500 ft.	747 ft. bel. tide.	650 ? lbs.	641 lbs.
Upper Sandusky, Well No. 1, ...	1280 "	478 " "	515 "	513 "
Bloom Tp., Wood Co., Godsend Well, ...	1145 "	395 " "	465 "	473.6 "
Findlay, Pioneer Well, ...	1120 "	336 " "	450 "	445.7 "
St. Mary's, Axe Well, ...	1159 "	238 " "	390 "	398.8 "
St. Henry's, Dwyer Well, No. 1, ...	1156 "	200 " "	375 "	385 "
Indiana.				
Kokomo, Well No. 4, ...	936 "	98 " "	320 "	332 "
Marion, Well No. 3, ...	870 "	78 " "	323 "	322.7 "
Muncie	900 ? "	At tide level.	300 ? "	286.6 "

These figures seem to me to settle the question as to the origin of the rock pressure of the gas in this formation. I feel sure that nicer determinations of the facts involved as to altitude and depth would bring a still closer agreement between columns four and five. I will ask you to note in particular the facts as to the St. Mary's and the St. Henry's wells. They have practically the same depth, 1159 and 1156 feet; but there is a difference of thirty-eight feet in the depth of the gas rock with reference to sea level. There is a corresponding difference in the rock pressure of fifteen pounds, as recorded. The difference in rock pressure due to this thirty-eight feet by calculation is 13.8 pounds, or practically fifteen pounds. I presume that column five is as near the truth in this particular as column four. The gauge would quite certainly be reported 385 pounds if it lacked but one or two pounds of that number.

The Laws of Gas Production.

The laws of gas and oil production and accumulation are coming to light more clearly in the flat country of Ohio and Indiana than they have ever done among the hills and valleys of the older Allegheny fields. As it seems to me, no more important deduction from the new districts has been reached than the law now stated, viz., *The rock pressure of Trenton limestone gas is due to a salt-water column, measured from about six hundred feet above tide to the level of the stratum which yields the gas.* The column can be conveniently counted as made up of two parts, viz., a fixed length of six hundred feet added to the depth of the gas rock below tide.

If this explanation is accepted as satisfactory for Trenton limestone gas, I venture to suggest that the fact will go a great ways toward rendering probable a like explanation for rock pressure in all other gas fields; but I will not at the present time venture to extend it beyond the limits I have named. I am aware of certain facts, or at least supposed facts, from the older fields that seem difficult of explanation on this basis.

There are a few obvious inferences from this law to which I venture to call your attention in closing this paper:

1. There is no danger that the great gas reservoirs of to-day will "cave in" or "blow up" after the gas is withdrawn from them. The gas will not leave the porous rock until the salt water obliges it to leave by driving it out and taking its place.

2. This doctrine lays the axe at the root of all the optimistic theories which blossom out in every district where natural gas is discovered, and especially among the real-estate operators of each new field, to the effect that Nature will not fail to perpetually maintain or perpetually renew the supplies which we find so delightfully adapted to our comfort and service. So far as we are concerned, it is certain that Nature has done about all that she is going to do in this line. In her great laboratory, a thousand years are as a single day.

3. No doctrine could exert a more healthful influence on the communities that are enjoying the inestimable advantages of the new fuel than this. If it were at once accepted, it would add years to the duration of these precious supplies of power. The ignorant and reckless waste that is going on in the new gas fields is lamentable. The worst of it comes from city and village corporations that are bringing the gas within their boundaries to give away to manufacturers whom they can induce on these terms to locate among them. To characterize the use of a million feet of natural gas a day, in a single town, for burning common brick, for example, or in calcining common limestone, there is a good word at hand, viz., *vandalism.*

4. If this doctrine of the rock pressure of gas is the true one, the geologists who have to deal with the subject and the communities that have found a supply owe it to themselves to keep it prominently before the people, who are especially inter-

ested. They may make themselves temporarily disagreeable thereby, but by just so far as they convince those that are interested, they lengthen the life of these precious supplies.

THE DURATION OF GAS SUPPLY.

Judging from the present indications, the Trenton limestone gas of Ohio is not likely to be long-lived. It seems entirely probable that the term of its further duration can be stated within the limits of numbers that are expressed by a single digit. In considerable sections of the field, the salt water is very aggressive. It requires a steadily increasing pressure on the wells to hold it back. In one district last year, one hundred and twenty-five pounds pressure would keep the gas dry, while now two hundred pounds are required for the same purpose.

There is likely to be great disappointment in regard to what is called gas territory. The pressure and volume of large areas are found to fail *together*. Wells draw their supply from long distances. A farm, or even a mile-square section, may be effectually drained of its gas without a well being drilled upon it.

Natural gas is a very admirable product, but its highest office, after all, should be to prepare the way for something better than itself, viz., artificial gaseous fuel—better, for the reason that while it furnishes all the intrinsic advantages of natural gas, it will be free from the inevitable disadvantages of treasures secured in the way in which the stores of the great gas fields have been gained.